Correlation Between Electrical and Mechanical Activation in the Paced Canine Heart

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Introduction

The purpose of this study was to quantify the relationship between the local electrical depolarization and mechanical contraction over the ventricular epicardium in vivo. The pattern of cardiac mechanical activation has been studied extensively using tagged MRI. By digitizing the tag motion, myocardial strain can be obtained throughout the entire heart over the cardiac cycle. We have developed a method to obtain electrical signals over the ventricular epicardium from the in vivo paced canine heart while the animal is in the MR scanner, immediately before or after image acquisition. By obtaining mechanical and electrical local activity, it is possible to make a whole-heart evaluation of the relationship between the two activation patterns. In this study, the cardiac electrical activation pattern is related to the epicardial temporal and spatial strain pattern in the ventricularly paced canine heart.

Methods

Thoracotomies were performed on two anesthetized dogs. For each dog, a 128-electrode epicardial sock was placed over the ventricular epicardium. Bipolar epicardial pacing electrodes were sewn onto the right atrium (RA) and right ventricle (RV). Pacing capture was established for RV pacing with the intrinsic electrical activation suppressed by simultaneously pacing the RA. The animal was then moved to the MR scanner where tagged cine images of the short and long axes of the heart were obtained during pacing. The imaging protocol was similar to that previously described (1). Between image acquisitions, electrical recordings were obtained from the sock electrodes. All epicardial recordings, as well as simultaneous LV pressure and pacing stimulus recordings, were obtained at an acquisition rate of 1500 Hz using customized software (HP VEE 5.0) controlling three synchronous 64-channel A/D boards (HP E1413C). The electrodes were RF filtered at the scanner patch panel and no pre-amplification was applied. After all images and electrical data were obtained, the animal was euthanized and the heart excised. The heart was filled with vinyl polysiloxane in order to maintain an end-diastolic shape and the sock electrode locations were recorded using a 3D digitizer (MicroScribe 3DLX).

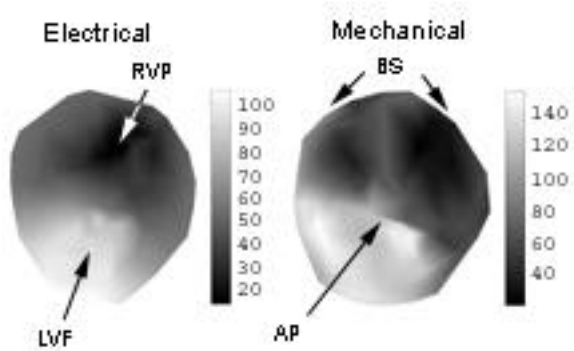

Figure 1 : 2D spatial plots of electrical and mechanical activation times (msec) for dog #1. RVP = right ventricular pace, LVF = left ventricular freewall, BS = base, AP = apex.

From the tagged images, circumferential strain was calculated throughout the cardiac cycle, using a four dimensional B-spline method previously described (2). The strain field was then evaluated on the epicardium in order to correlate with electrical recordings. The time of onset of local mechanical activation, defined here as the point at which the myocardium begins to shorten, was chosen using a semi-automated method. Unipolar voltage readings from each electrode were averaged over approximately 20 heartbeats and electrical activation times were chosen as the most negative 5-point derivative. Both electrical and mechanical activation times were referenced to the pacing stimulus. Spatial correlation between electrode locations and locations of mechanical evaluation was achieved by aligning the cardiac long axes of both data sets and finding the relative rotation about that axis that minimized activation delay over the heart.

Results

Mechanical and electrical activation maps, temporally referenced to the pacing stimulus, were obtained from the epicardial surface (see Figure 1). A delay between local electrical and mechanical activation was observed over the entire epicardial surface. As the electrical activation propagates from the pacing site, the mechanical response becomes increasingly delayed according to the linear relationship M=kE + d (see Figure 2). This electromechanical relationship is consistent between the two hearts studied with a slope of 1.35 in one heart and 1.46 in the other.

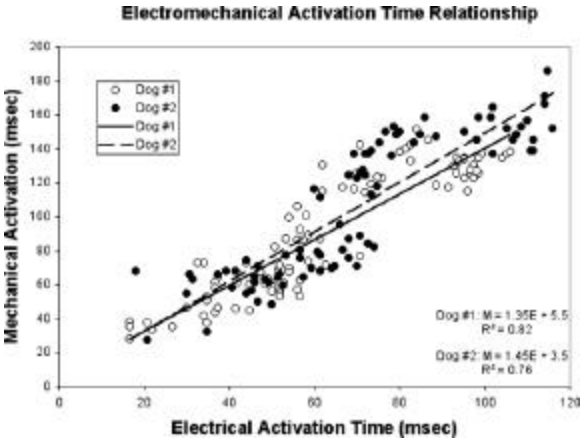

Figure 2 : Electrical and mechanical activation times for correlated points on the epicardium.

Discussion

We have developed a method for obtaining electrical and mechanical activation information over the entire ventricular surface in vivo in the MR scanner. Because electrical data and MR images are acquired within a few minutes of each other, and no animal intervention occurs in between the two acquisitions, the electromechanical relationship can be studied at the whole-heart level for numerous physiologic states. For this preliminary study, we have chosen to focus on the relationship between the propagation of the electrical stimulus and the mechanical response in the RV-paced heart.

The early-activated regions of the heart were contracting against relaxed tissue on the opposite wall, while the later activated regions were contracting against contracted tissue. This late-activated tissue may therefore have taken longer to develop the force necessary to develop detectable negative strain, producing the distinct increase in mechanical delay for later activated tissue (see Figure 2).

The range of mechanical activation times observed for a specific electrical activation contour was quite large. We are now investigating alternative definitions of mechanical activation that correlate more tightly to the electrical activation data.

Acknowledgements

The authors would like to acknowledge Jayne Davis and the entire Nora Eccles Harrison Cardiovascular Research and Training Institute at the University of Utah for their design and construction of the cardiac sock. We would also like to acknowledge Scott Chesnick and Burton Chidakel.

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